AN OVERVIEW OF THE AIRCRAFT CRASHWORTHINESS STUDY PROJECT “A EUROPEAN PROGRAMME”

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Abstract

This paper describes the European research effort aimed at the development of crashworthy aircraft. Within the European community a research programme was undertaken to provide a basis for improved aircraft safety and to enhance European knowledge and capabilities with respect to crashworthiness for commercial aircraft. The first phase of the programme which concerned metallic fuselage and called “Crashworthiness” started in 1993 and completed in 1997. The current design for crash survivability called “CRASURV” focuses mainly on the composite fuselage structure and its capability to absorb energy. The former programme involved extensive analytical studies which were supported by experimental work on materials, components and full-scale structures. Non-linear dynamic analysis methodologies were further developed and validated for specific application to the commercial aircraft environment. The aim was to provide an integrated approach to crashworthiness problem as well as occupant protection assessment when subjected to aircraft crash impulse in terms of occupant interaction with the surrounding structure. Both programmes have been funded by EC and involved major European aircraft manufacturers, software developers, test houses, research centres and universities.

1. Programmes Objectives

This paper demonstrates an overview of the work by highlighting the results achieved with presentation of a selection of the technical achievements. As part of an extensive effort by the European Community to enhance European knowledge and capabilities with respect to crashworthiness, the programme on crashworthiness for commercial aircraft, "Crashworthiness" in Framework III was funded by the European Commission (EC), (Ref. 1). The design guidelines resulting from this is of prime importance for the demonstration of airworthiness, and could provide a basis for improved aircraft safety and enable the European regulatory bodies to play a more significant role in the future airworthiness requirement.

Cranfield Impact Centre is a also participant in the European Community Programme "CRASURV" in Framework IV, (Ref. 2). The object of this programme, which is still in progress, is to develop technology for the design of composite airframe with maximum safety with respect to potentially survivable crash scenarios.

The use of composite materials in airframe component manufacturing is becoming widespread and the understanding of how they behave under load is developing continuously. The programme aims at building enhanced capability to accurately predict the behaviour of airframes, made primarily of composite materials, for a number of well-defined crash scenarios by numerical simulations and to assess the occupant response accordingly.

2. Programme Overview - "Crashworthiness" Project

In Figure 1 the project management structure shows the participants in the "Crashworthiness" programme. With the exception of TNO and Fokker and inclusion of Alenia(Italy), University of Limerick|(Ireland IE), Principia(Spain), Patec(Denmark) and Dassult Aviation(France), all the other participants are involved in the current "Crasurv" project. Twenty one partners from nine European Union (EU) countries were involved. They represent major airframe manufacturers, national aerospace establishments, advance structural test centres, software technology centres, universities and small industry.

The programme provided an excellent opportunity to combine European expertise in advanced structural mechanics and aeronautics to achieve objectives in improving passenger safety in moderate and survivable air crashes. An additional benefit was to enhance capabilities in crashworthiness and thus strengthen the European role in international airworthiness requirements, discussions and rule making.

In Figure 2 the project technical work is shown. The programme was divided into four inter-linked main sub-tasks:-

- Establishment and distribution of background data.
- Establishment, verification and comparison of analysis methodologies.
- Studies of major airframe structure.
- Studies of occupant and local structure.

In Task 1, a thorough survey of the existing airworthiness requirements, survivable crash scenarios, human injury, critical and numerical modelling data including past aircraft structural impact tests were investigated. Information and data on 176 accidents between 1959-1979 and a further 123 between 1980-1992 were investigated. A review of the 1989 Kegworth accident and several U.S. crash tests were carried out.

Task 2, in which CIC was responsible for co-ordination, dealt with the establishment, verification and comparisons of analysis techniques. The methodology adopted was to investigate different available methods of analysing the behaviour of aircraft structures and their occupants. The work involved Hybrid and Finite Element analysis methods, together with occupant and seat simulation. These analytical techniques were supported by a series of static and dynamic tests on materials and airframe components. A number of static and dynamic component tests, including a mini drop test, were performed at CIC on various parts of an Airbus A320 fuselage, Figure 3, (Ref. 18). Material tensile tests, and, rivet joint tests, both static and dynamic, were performed on the samples taken from the A320 and also from the raw mill condition alloys, Figure 4(a,b), (Ref. 6). The results indicated that for range of strain rates examined, strain rate had little influence on the 0.2% yield stress and ultimate tensile stress values. However, strain rate does not appear to influence the rupture strain and reduction in area values. In the case of rivet joints two basic failure modes, material failure and complete rivet shear, were identified (Ref. 6).

The principal connecting members in an aircraft structure is the rivet. The behaviour of rivet joints and their failure loads both in tension and shear are of prime importance. Figure 5 shows a Radioss F.E. model of a rivet in which non-linear ‘beam-spring’ elements between nodes of the meshing has been used to model the rivets (Ref. 17).

The aim of the project was also to determine the most effective analysis methodologies for increasing the level of safety in moderate commercial aircraft crashes. The study led to the development of Hybrid codes to make them effective in simulating global collapse modes of aircraft in a less complex and quicker way than F.E. codes.

Three major F.E. codes were used and further developed to cater for the airframe materials and collapse behaviour. The aim was to determine an effective modelling methodology for aircraft structures. The methodology topics, the details of which is highlighted in (Refs. 4 & 5) , investigated were:-

- General modelling problems.
- Behaviour problems.
- Various types of analysis and simulation methods.

The codes development, seen as powerful tools in analysing the response of structures to crashes, together with the F.E. models and test verification, demonstrated that impact phenomena are now well understood and the technology is available for carrying out the analysis. The limitation factors are the current machine capacity and the complexity and size of the models.

Occupant response under various input conditions by way of modelling were carried out. Verification of the response of seats and occupants were achieved through a set of test programmes. Dynamic sled tests, in accordance to FAR/JAR 25.562 requirements, were performed with 2 seat rows, Figure 6, (Ref. 8). The aim was to provide data for validation of the computer models, using Madymo, for various seat/occupant/restraint configurations and loading conditions, Figure 7, (Ref. 7).

Task 3 involved study of major airframe structures. There were two main objectives in this task. The first was to validate the modelling methodologies developed under Task 2, for materials and components, when applied to a full-scale structure. A full-scale drop test of a fuselage section (A320 rear fuselage), shown in Figure 8, was performed. Both pre and post-test Hybrid and F.E. analysis approaches were used to simulate a full-scale drop test. A section of A320 comprising of 6 frames (5 bays), with representative masses of seats and dummies was modelled using different F.E. codes. Evaluation of the F.E. models of the Drop Test was based on the model build-up from component level carried out in Task 2, to full-scale level in Task 3. The limitations of dealing with large F.E. models due to their size and complexity, in particular, run time, as shown in Table 1, were also highlighted. Selected results for both F.E. and Hybrid KRASH models are shown in Figure 9(a,b).

Model by	No. of Shell Elements	No. of Rivets or Rigid Bodies	Simulation Time (ms) / CPU (hrs)	F.E. Codes	Machines
Aerospatiale	174017	9182	100 / 110	RADIOSS	Cray J916
BAe Airbus	103797	------	200 / 104 200 / 64	LS-DYNA	Cray J90 Cray YMP
CASA	147089	13104	300 / 150	PAM-CRASH	Cray YMP
CIC**	174018	7676	150 / 95	PAM-CRASH	Cray J90

Table 1 - Drop Test F.E. Model Details and Process Parameters
** Aerospatiale Pre-test Radioss Model Conversion to Pam-Crash

The second objective was to improve airframe design by understanding the physical phenomena during the crash of an aircraft section and associated failures and injuries. Critical areas of the airframe were identified and sensitivity studies were carried out for comparisons with the test results. Although the drop tests are very valuable in terms of collection of information, they are only partly representative of crashes and the results should be manipulated and understood in that context.

In Task 4, studies of occupant and local structures was carried out. Hybrid and F.E. methods were used to study aircraft local structures and modelling interactions between occupants, seats and restraint systems. The analytical investigation was supported by extensive test programme. The task examined the effects of impact on the passenger directly. The floor/sub-floor structures were investigated for five different types of aircraft, A320, Fokker 100, Fokker 50, CASA C212 and CASA CN-235.

Injuries and fatalities can be caused by free-flying objects within the cabin. Luggage bins can either be detached or open under dynamic load. Two dynamic sled tests involving overhead luggage bins were performed to represent two different impact scenarios, a combined vertical and longitudinal test and a test with a predominantly longitudinal deceleration component. In both tests two conditions corresponding to the requirements for static design load and the loading required for the seat rows, JAR/FAR 25.562, (Ref. 3), were tested. Finite Element analysis of luggage bin behaviour demonstrated areas where improvements could be made. The work in this area was limited and did not point to the need for further investigation.

Also investigated was detailed F.E. modelling of the cabin attendant seat and the attendant kinematics response, Figure 10, (Ref. 9). Seat floor connections were examined. Seat structural components and restraint systems were studied. Effects of crash forces on adults and children were analysed. Valuable information were obtained on injury indices and characteristics and recommendations were made to reduce injuries.

3. “CRASURV” Project

In the "CRASURV" programme, an extensive investigation of composite material behaviour, through testing and study of failure mechanisms, followed by development of numerical computer codes, under impact conditions are being carried out. The developed codes, using the new material models, were used to analyse the generic composite structures with proven crashworthy properties. Tests on the full-scale airframe structures constructed from composite materials will be used to validate the numerical simulations, using codes such as, LS-Dyna, Pam-Crash and Radioss. Also investigated will be the occupant behaviour with respect to crashworthiness of the composite fuselage structure.

Cranfield Impact Centre's role in the "CRASURV" programme is to perform numerical simulations of impact surfaces, using the LS-Dyna finite element software. An extensive search was conducted to collect material data for soil properties which were then translated into appropriate material model formats to describe the various ground types such as sand, sand and gravel mixture and concrete. Assessment of impact surfaces material model was made. Response of the soft soil is shown in Figure 11, (Refs. 19, 20). The soil models were used to study dynamic response of composite airframe structures. Also investigated by CIC is the determination of the passenger response to composite fuselage deceleration pulses and cabin interior design. Assessment of influence of cabin seat layouts, restraint systems and protective covering upon passengers injury indices have been made, using Pam-Crash software, Figure 12.

4. Conclusions

The two programmes have shown that exploitation of relevant skills within Europe, by developing an essential knowledge base and tools for the advancement of aircraft design, can add value to its aerospace industry.

The main achievements of the "Crashworthiness" programmes were:-

- Validated methodology for non-linear dynamic hybrid analysis of commercial aircraft crashes.
- Validated methodology for non-linear dynamic finite element analysis of commercial aircraft crashes.
- Validated methodology for occupant modelling in a commercial aircraft crash.
- Correlation of the hybrid and finite element techniques with test work for materials, components and full-scale structure.
- Design guidelines for improved crashworthiness of a commercial aircraft.
- Mechanical characteristics of aeronautical materials and assembly methods.
- Interactions with end users (e.g. operators) have shown the work relevant to them by elevating their awareness of the new techniques and technologies concerning significant advancements in passenger safety enhancement and greater European competitiveness in aircraft design.

Overall evaluation of the F.E. codes used in the programme showed that the general modelling such as mesh refinement, joints (rivets) model, shell element formulation choice were dominant factors for strength and weakness of a model.

For detailed large F.E. models, the programme showed that, given the available computer resources, the model size can limit the quality of the analysis to some extent. The investigation also revealed that rivets which are the main connecting members in a aeronautical structure, can be adequately modelled in F.E. codes. It is, however, important that material embrittelment due to rivet holes should be given additional modelling consideration.

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